

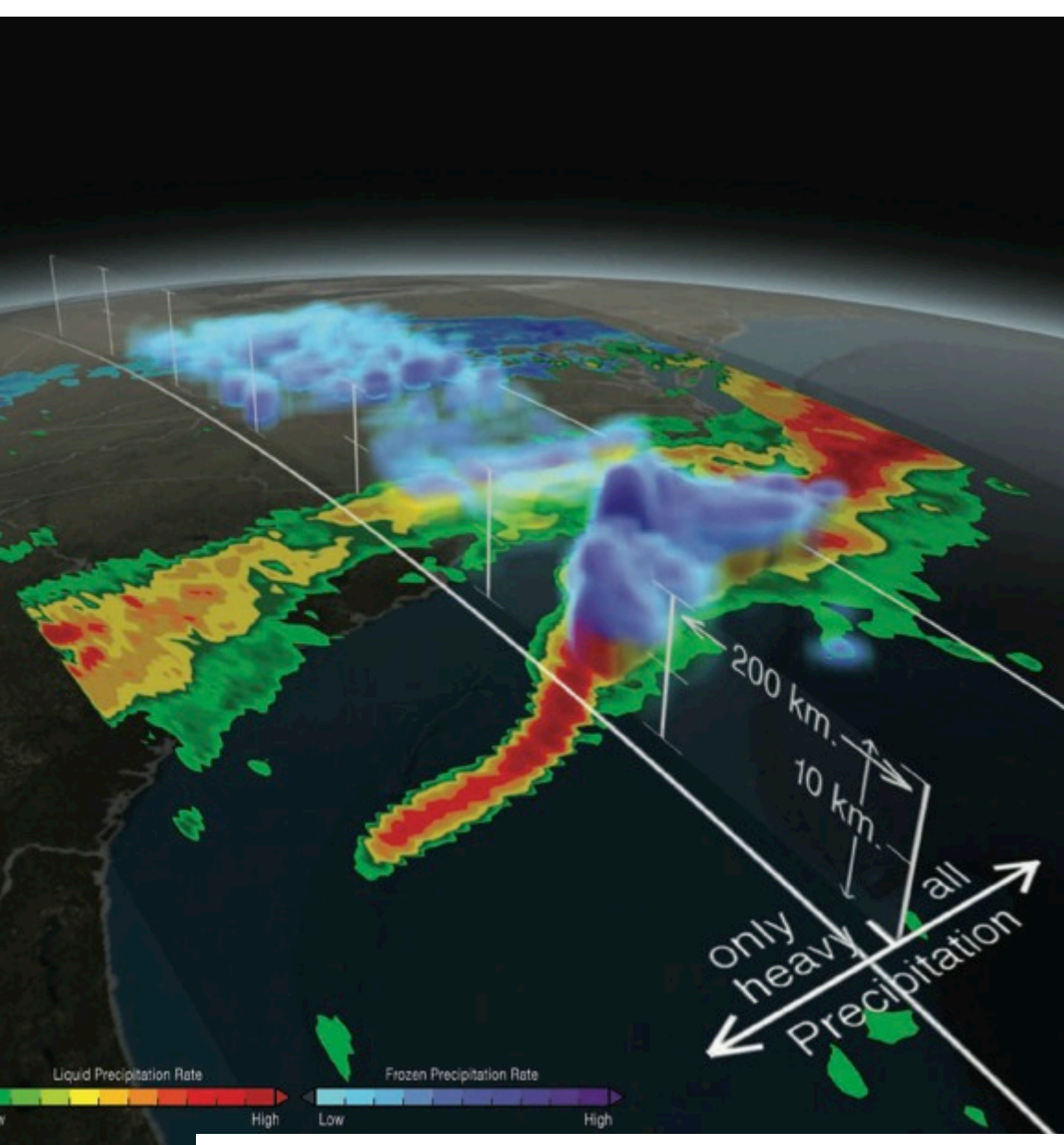
# Global Precipitation Measurement (GPM) Microwave Imager Falling Snow Retrieval Algorithm Performance

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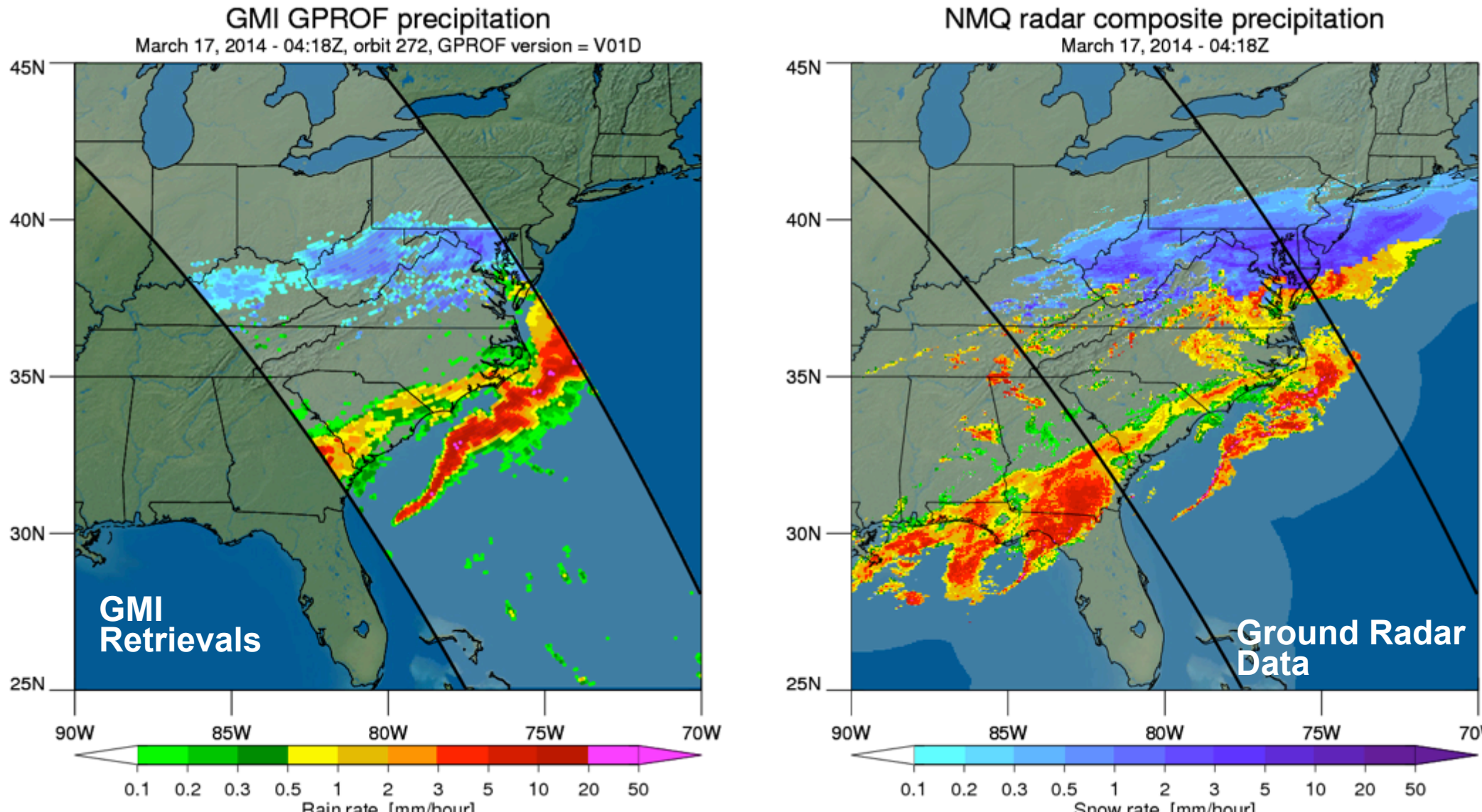
**Introduction:** Precipitation falling in the form of snow is critically important for society and the Earth’s climate, geology, agriculture, and ecosystems. Falling snow can exert tremendous socio-economic impacts and disrupt transportation systems. In some parts of the world, snow is the dominant precipitation type and relied upon year round for freshwater. **Despite their importance for human activity and understanding of the Earth’s system, measuring falling snow remains a challenge.**

Furthermore, it is difficult to obtain global and fully representative measurements of both rain and snow with ground based instruments. Satellite based observations are useful in obtaining near-surface falling snow estimates. Indeed, the recently launched Global Precipitation Measurement (GPM) mission was specifically designed to remotely sense (estimate) both liquid rain and falling snow. This poster describes the **early results and performance evaluations of estimating falling snow** using the GPM Microwave Imager (GMI) algorithm.



### GPM Detects Falling Snow

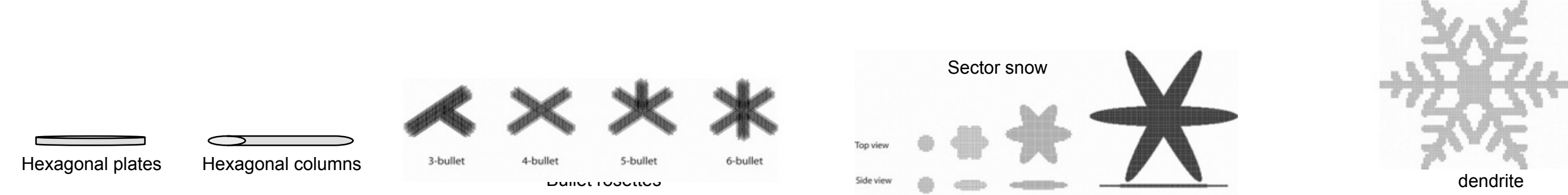
← This image, from March 17, 2014 (just 18 days after GPM’s launch), shows one of the first snow events measured by GPM. It shows the southern extent of a falling snow storm off the coast of South Carolina. Inside the storm over the Atlantic ocean, precipitation was frozen at high altitudes in the cloud before melting into rain near the surface. Inland, the temperatures were below freezing all the way down to the surface, allowing the formation of shallow, low-level (i.e., nimbostratus) clouds capable of producing snow. This event produced 7” of snow in Washington, DC.



Above: These are the validating imagery for the March 17, 2014 snow storm. **Above Left:** GMI retrievals of liquid rain (greens to reds indicate light to heavy rain) and falling snow (blue shading). **Above Right:** Ground observations from NOAA’s National Mosaic & Multi-Sensor QPE (CONUS 3D radar mosaic at 1km resolution). Note that over Kentucky, GPROF retrieves while NMQ does not. This needs to be investigated further.

### Radiative Transfer Calculations: Active and Passive

The radiative transfer equations rely on the planar-stratified, multiple scattering based model described in [Skofronick-Jackson *et al.*, 2004]. These calculations are performed at the resolution of the simulations (1 km) and for each of the 207,000 profiles in the WRF domain of a Jan20-22, 2007 event (Shi *et al.*, 2010). **TBs at the GMI channels were computed.** For the Z computations, we use the reflectivity eqns found in Meneghini *et al.*, [1997]. Reflectivity range gates are the WRF vertical layers. **Zs were computed for Ku, Ka, and W-bands.** For the snow and graupel particles, randomly oriented, non-spherical particles from G. Liu’s database [2004] are used described in Skofronick-Jackson and Johnson (2011). **TBs and Z were computed for all 11 snowflake shapes.**



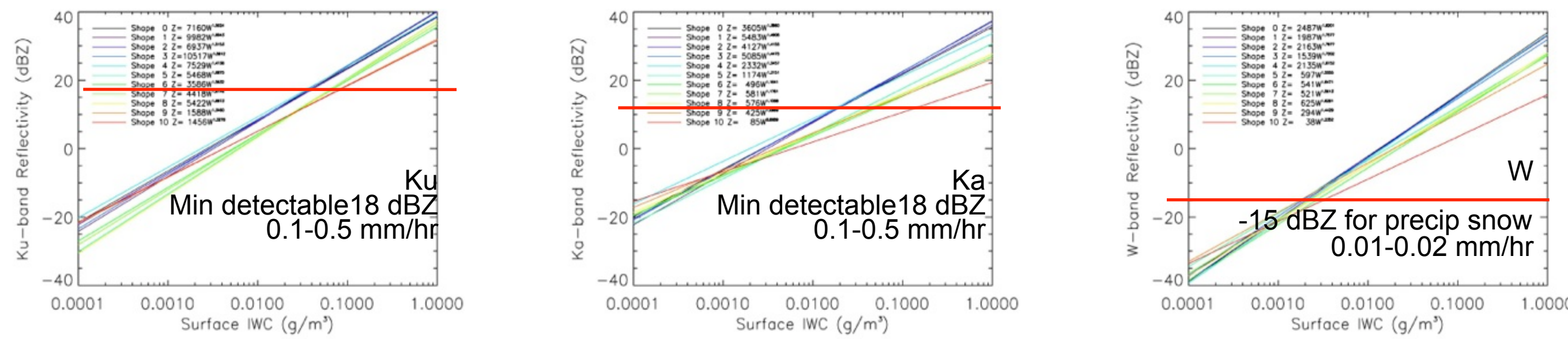
### Overall Threshold Perspective

Passive microwave retrievals over land are challenging due to the contamination from surface emission, but falling snow detection is achievable. The notable results show: (1) the W-Band radar has detection thresholds more than an order of magnitude lower than the future GPM sensors, (2) the cloud structure macrophysics influences the thresholds of detection for passive channels, (3) the snowflake microphysics plays a large role in the detection threshold for active and passive sensors, (4) with reasonable assumptions, the passive 166 GHz channel has detection threshold values comparable to the GPM DPR Ku and Ka band radars **with ~0.05 g m<sup>-3</sup> detected at the surface, or an ~0.5-1 mm hr<sup>-1</sup> melted snow rate (equivalent to 0.5-2 cm hr<sup>-1</sup> solid fluffy snowflake rate).**

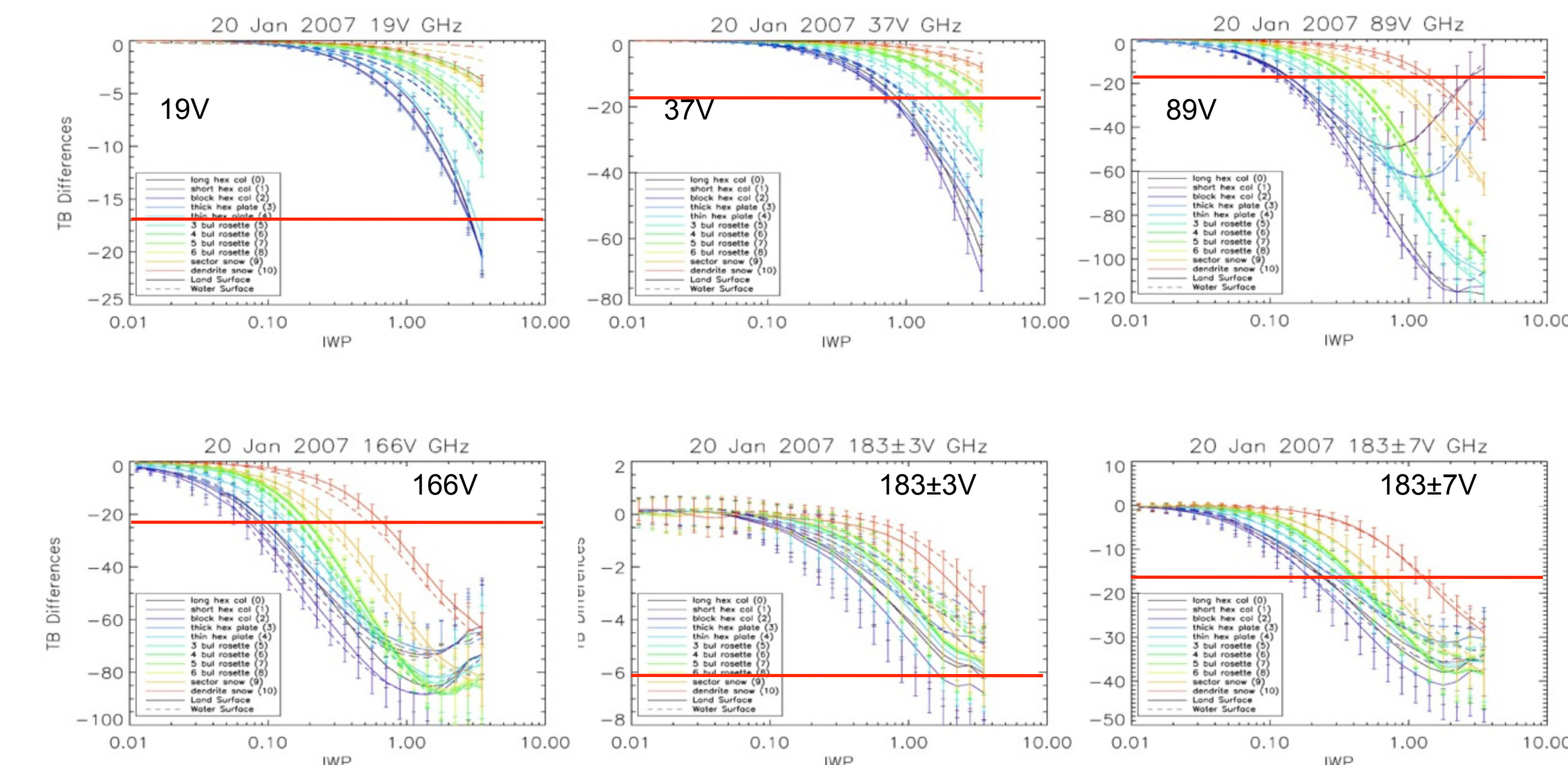
### Thresholds of Falling Snow Detection

Passive microwave retrievals over land are challenging due to the contamination from surface emission, but falling snow detection is achievable. From Skofronick-Jackson *et al.*, 2014, the notable results show: (1) the W-Band radar has detection thresholds more than an order of magnitude lower than the future GPM sensors, (2) the cloud structure macrophysics influences the thresholds of detection for passive channels, (3) the snowflake microphysics plays a large role in the detection threshold for active and passive sensors, (4) with reasonable assumptions, the passive 166 GHz channel has detection threshold values comparable to the GPM DPR Ku and Ka band radars **with ~0.05 g m<sup>-3</sup> detected at the surface, or an ~0.5-1 mm hr<sup>-1</sup> melted snow rate (equivalent to 0.5-2 cm hr<sup>-1</sup> solid fluffy snowflake rate).** Additional efforts will constrain the process to improve algorithms to distinguish rain, clear-air, snow, and indeterminate cases. Observational analysis (Munchak and Skofronick-Jackson 2013) confirm the 0.5 mm/hr threshold rate.

### Analysis: Radar Reflectivities: 11 Snowflake Shapes



### ΔBrightness Temperatures (ca-sim): 11 Snowflake Shapes



### Relevant References

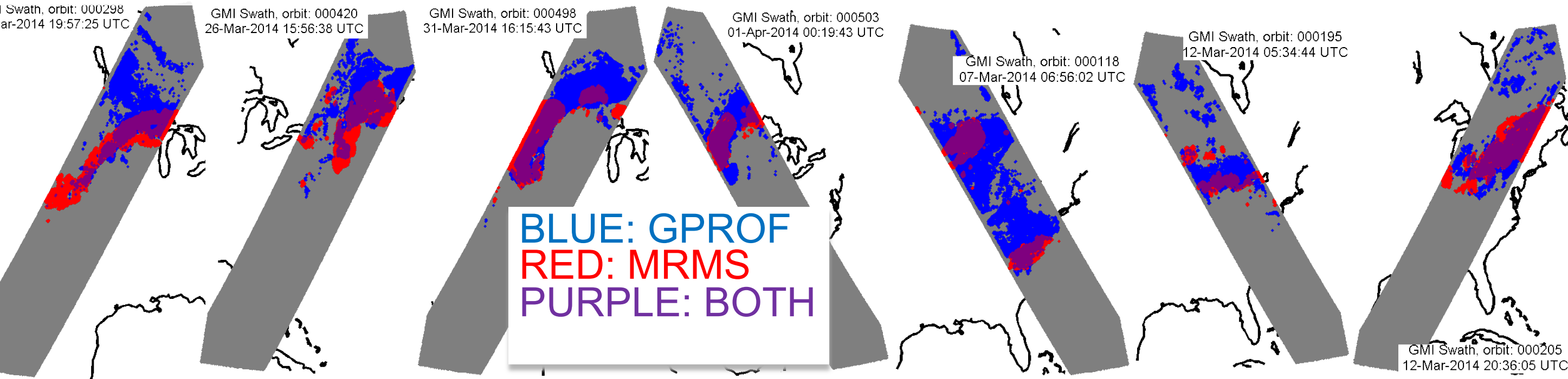
1. Skofronick-Jackson, G.M.; Johnson, B.T.; Munchak, S.J., "Detection Thresholds of Falling Snow From Satellite-Borne Active and Passive Sensors," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 51, no. 7, pp. 4177 - 4189, July 2013 doi: 10.1109/TGRS.2012.2227763
2. Munchak, S.J., Skofronick-Jackson, G., Evaluation of precipitation detection over various surfaces from passive microwave imagers and sounders, *Atmos. Res.* (2012), <http://dx.doi.org/10.1016/j.atmosres.2012.10.011>
3. G. Skofronick-Jackson and B. T. Johnson, "Surface and Atmospheric Contributions to Passive Microwave Brightness Temperatures for Falling Snow Events," *J. Geophys. Res.*, 116, D02213, doi:10.1029/2010JD014438, 2011.
4. J. J. Shi, W.-K. Tao, T. Matsui, R. Cifelli, A. Hou, S. Lang, A. Tokay, C. Peters-Lidard, G. Skofronick-Jackson, S. Rutledge, and W. Petersen "WRF Simulations of the 20-22 January 2007 Snow Events over Eastern Canada: Comparison with in-situ and Satellite Obs.," *J. Appl. Met. Clim.*, Oct. 2010.
5. G. M. Skofronick-Jackson, M.-J. Kim, J. A. Weinman, and D.-E. Chang, "A Physical Model to Determine Snowfall over Land by Microwave Radiometry," *IEEE Trans. Geosci. Remote Sens.*, 1047-1058, 2004.
6. Liu, G., 2004: Approximation of single scattering properties of ice and snow particles for high microwave frequencies. *J. Atmospheric Sci.*, 61, 2441-2456.
7. Gail Skofronick-Jackson, Walter Petersen, David Hudak, Steve Nesbitt, and others, Global Precipitation Measurement Cold Season Precipitation Experiment (GCPEX): For Measurement Sake Let it Snow), revision submitted to BAMS Oct. 2014.

### GMI Retrieval Algorithm GPROF compared to Multi-Resolution Multi-Sensor (MRMS) Ground Truth

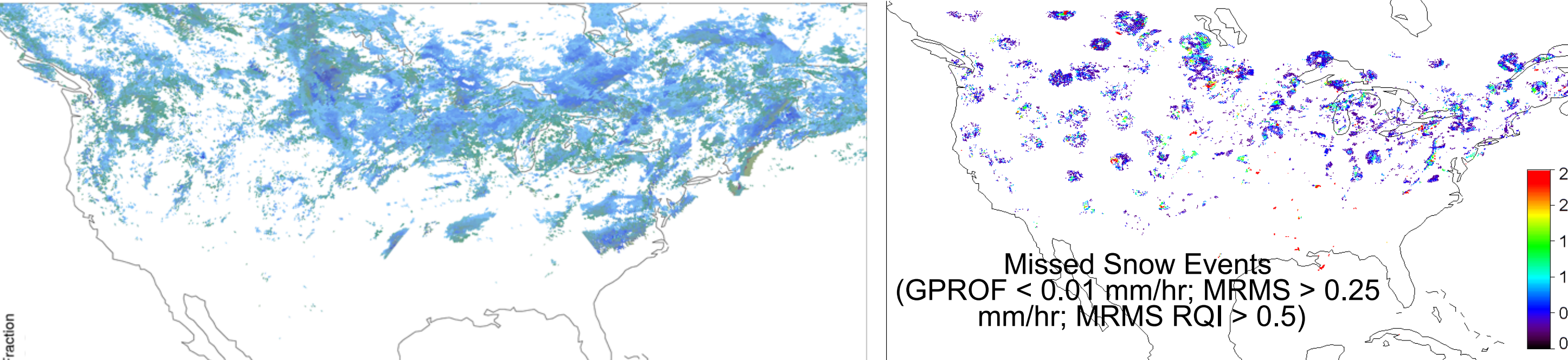
**MRMS/NMQ:** Gridded 0.01x0.01 degree, every 2 minutes, CONUS wide (20N-55N), gauge-bias adjusted radar rainfall rates with a quality index, type indicator (warm stratiform rain, warm stratiform rain at ground but radar data is in or above the melting layer, snow, snow at ground but radar data is 1.5km/ or higher above the ground, convective, hail, tropical/stratiform rain mix, tropical/convective rain mix, cool stratiform rain). The NMQ Level II/III products include a liquid equivalent snow rate (based on Z-R). Errors will be large for this estimate, but GPM requirement is detection, and it can be used for this purpose.

**GPROF:** The Goddard Profiling Algorithm (GPROF) is a “Bayesian” algorithm for near-surface rainfall rate and snowfall rate retrieval (Kummerow *et al.*, 2001). The GPROF 2014 data used in this analysis are “version 1-3” for the hit/miss maps below. The Detection Plot just below uses version 1-4. The matchups were done using the GMI 37 GHz footprint to generate weighting functions for the MRMS data. Only footprints where the GPROF liquid fraction was less than 50% and the MRMS radar quality index was greater than 0.5 were considered, in order to isolate snow cases where the radar quality ensures detection of falling snow (low beam elevation without significant blockage).

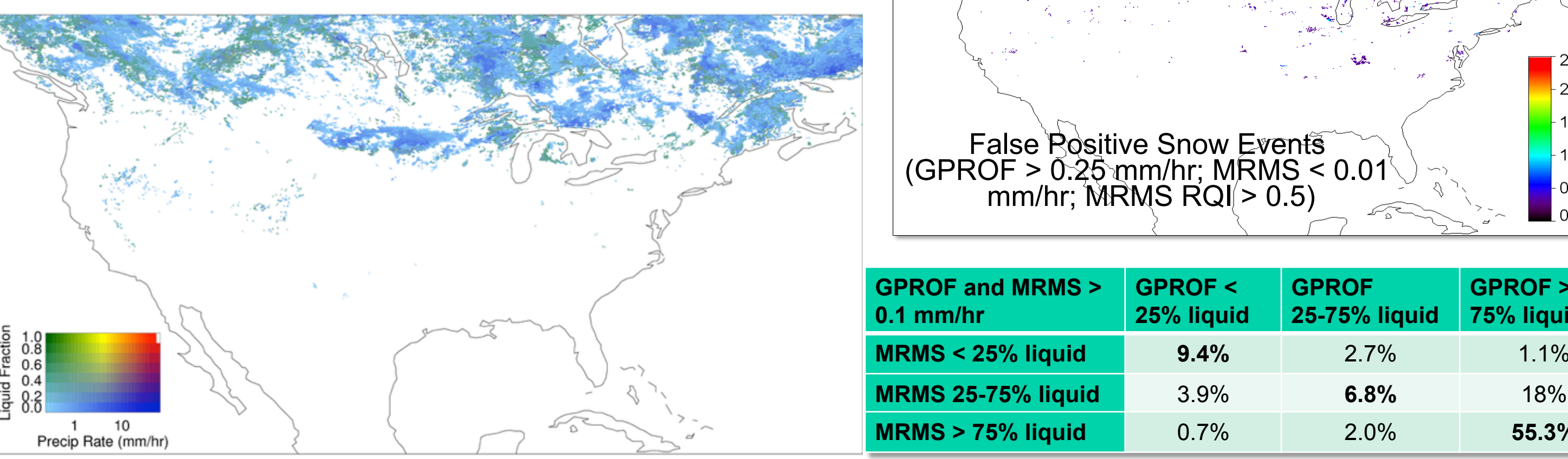
### Precipitation Detection using GPROF and MRMS (Johnson)



### All GMI-GPROF falling snow retrievals, March-April 2014 (Johnson)



### All GMI-GPROF falling snow retrievals, Oct 1-Nov 12, 2014



GPROF and MRMS > 0.1 mm/hr		GPROF < 25% liquid	GPROF 25-75% liquid	GPROF > 75% liquid
MRMS < 25% liquid	9.4%	2.7%	1.1%	
MRMS 25-75% liquid	3.9%	6.8%	18%	
MRMS > 75% liquid	0.7%	2.0%	55.3%	

### Future Work and Acknowledgments

Our next steps include: (1) incorporating our observational and simulated Bayesian database into the official GPM radiometer database, (2) verifying that ice scattering above rain does not contaminate these falling snow retrievals, (3) repeating analysis with GCPEX (Jan – Feb 2012 field campaign data) & (4) further analyze GMI retrievals.

We thank all the team members and PI's of the C3VP & GCPEX experiment, especially Dave Hudak of Environment Canada (overall C3VP PI), Ali Tokay (for the Parsivel data), Dr. Tao, Roger Shi and Tao's team (for the WRF model data), and Steve Nesbitt (for the King City images and data). Funding for this work comes from NASA Headquarters and PI (Skofronick-Jackson) for PMM (Ramesh Kakar) and CloudSat (Hal Maring) grants